Example 11.8

The following parameters are established for a long-haul single-mode optical fiber system operating at a wavelength of 1.3 km.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean power launched from the laser transmitter</td>
<td>-3 dBm</td>
</tr>
<tr>
<td>Cabled fiber loss</td>
<td>0.4 dB km</td>
</tr>
<tr>
<td>Splice loss</td>
<td>0.1 dB km</td>
</tr>
<tr>
<td>Connector losses at the transmitter and receiver</td>
<td>1 dB each</td>
</tr>
<tr>
<td>Mean power required at the APD receiver:</td>
<td></td>
</tr>
<tr>
<td>when operating at 35 Mbits⁻¹ (BER 10⁻⁶)</td>
<td>-55 dBm</td>
</tr>
<tr>
<td>when operating at 400 Mbits⁻¹ (BER 10⁻⁹)</td>
<td>-44 dBm</td>
</tr>
</tbody>
</table>

\[
\text{Required safety margin} = 7 \text{ dB}
\]

Estimate:

(a) the maximum possible link length without repeaters when operating at 35 Mbits⁻¹ (BER 10⁻⁶). It may be assumed that there is no dispersion–equalization penalty at this bit rate.

(b) the maximum possible link length without repeaters when operating at 400 Mbits⁻¹ (BER 10⁻⁹) and assuming no dispersion–equalization penalty.

(c) the reduction in the maximum possible link length without repeaters of (b) when there is a dispersion–equalization penalty of 1.5 dB. It may be assumed for the purposes of this estimate that the reduced link length has the 1.5 dB penalty.

Solution: (a) When the system is operating at 35 Mbits⁻¹ an optical power budget may be performed using Eq. (11.53), where

\[
P_t - P_0 = (\alpha_{lc} + \alpha_j) L + \alpha_{er} + M_a \text{ dB}
\]

3 dBm - (-55 dBm) = (\alpha_{lc} + \alpha_j) L + \alpha_{er} + M_a

Hence,

\[
(\alpha_{lc} + \alpha_j) L = 52 - \alpha_{er} - M_a
\]

\[
0.5 L = 52 - 2 - 7
\]

\[
L = \frac{43}{0.5} = 86 \text{ km}
\]

(b) Again using Eq. (11.53) when the system is operating at 400 Mbits⁻¹:

\[
P_t - P_0 = (\alpha_k + \alpha_j) L + \alpha_{er} + M_a
\]

-3 dBm - (-44 dBm) = (\alpha_k + \alpha_j) L + \alpha_{er} + M_a

\[
\left[ (\alpha_k + \alpha_j) L = 41 - 2 - 7 \right]
\]

\[
L = \frac{32}{0.5} = 64 \text{ km}
\]

(c) Performing the optical power budget using gives:

\[
P_t - P_0 = (\alpha_k + \alpha_j) L + \alpha_{er} + M_a
\]

Hence,

\[
0.5 L = 41 - 2 - 1.5 - 7
\]

and

\[
L = \frac{30.5}{0.5} = 61 \text{ km}
\]
Rise-Time Budget Example

System

\[ A = 830 \text{ nm} \]
\[ B = 100 \text{ Mbps/sec} \]
\[ BER = 10^{-9} \]

Utilize an LED with a rise-time of 8 ns and a spectral width of 40 nm (Is it band-width limited?)

Silica fiber has \( \frac{\Delta^2}{\frac{dn}{d\lambda}} \approx 0.024 \) (unit-less)

Use a graded index fiber with a 50 \( \mu \)m core diameter, numerical aperture of 0.25 and an intermodal dispersion of 3.5 ns/km

length \( L = 2.5 \text{ km} = l \)

PIN diode detector with rise-time = 10 ns

a) Calculate the system rise-time \( \Delta t_{sys} \)

\[
\Delta t_{sys} = \left( (\Delta t_s)^2 + (\Delta t_R)^2 + (\Delta t_{mat})^2 + (\Delta t_{modal})^2 \right)^{\frac{1}{2}}
\]

\[
\begin{align*}
\text{source} & \quad \text{detector} & \quad \text{material} & \quad \text{modal} \\
8 \text{ nsec} & \quad 10 \text{ nsec} & \quad & \quad
\end{align*}
\]

\[
\frac{L}{c} \frac{\Delta^2}{\frac{dn}{d\lambda}} \approx 3.5 \times 2.5
\]

\[
= \frac{2.5 \times 10^3}{3 \times 10^8} \times 40 \times 0.024
\]

\[
= 9.64 \text{ nsec}
\]

\[
= 18.3 \text{ nsec}
\]

To estimate the bit rate, \( B \)

bit period is \( \frac{1}{B} = T_B \)

Generally require system rise-time to be less than 70% of the bit-period for NRZ

Thus for NRZ

\[ B_B \leq \frac{1}{\Delta t_{sys}} \leq 38 \text{ Mbps}^{-1} \]

and for RZ

\[ B_R \leq \frac{1}{9 \text{ nsec}} \leq 19 \text{ Mbps}^{-1} \]
Star Network Power Budget

We begin by calculating the power budget for a star network. Consider the power entering a fiber at the input to a coupler, $P_F$, and the power required by the receiver, $P_R$. We will assume an insertion loss, $L_{\text{insert}}$, a power splitting loss, $L_{\text{pwr split}}$, a connector loss, $L_C$, a system margin, $L_M$, and a fiber loss, $\alpha$ (dB/km). If $L$ is the distance from the star coupler to each station, the path of the power from the transmitter to the receiver would be as follows:

- $P_F$ in the fiber at the transmitter,
- a fiber loss of $\alpha L$ in going from the transmitter to the star,
- a loss of $L_C$ as the light passes through the fiber/coupler connector pair to enter the star coupler,
- a loss of $L_{\text{pwr split}}$ as the power is divided among the output fibers of the star,
- a loss of $L_C$ as the power passes through coupler/fiber connector pair leaving the star coupler,
- an additional loss of $L_{\text{insert}}$ due to the insertion loss of the star coupler, and
- a fiber loss of $\alpha L$ in going to the receiver. (We assume ideal coupling into the receiver.)

Adding up all of these dB losses, the link power budget would be

$$10 \log(P_F/P_R) = L_{\text{pwr split}} + \alpha(2L) + 2L_C + L_{\text{insert}} + L_M \quad (8.1)$$

$$= 10 \log N + \alpha(2L) + 2L_C + L_{\text{insert}} + L_M,$$